

**Plant physiological and biophysical regulations of ecohydrological
processes in response to strong climate variability**

Rong Gan

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University of Technology Sydney
Australia

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Certificate of Original Authorship

I, Rong Gan declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Life Sciences/Faculty of Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Glossary

ET	<i>evapotranspiration (mm d^{-1})</i>
E	<i>evaporation from wet surface (mm d^{-1})</i>
T	<i>transpiration from vegetation (mm d^{-1})</i>
GPP	<i>gross primary production ($\mu\text{mol m}^{-2} \text{s}^{-1}$ or $\text{g C m}^{-2} \text{d}^{-1}$)</i>
Q	<i>Streamflow (mm d^{-1})</i>
LE	<i>latent heat flux (W m^{-2})</i>
H	<i>sensible heat flux (W m^{-2})</i>
G	<i>ground heat flux (W m^{-2})</i>
CO ₂	<i>carbon dioxide</i>
C _a	<i>atmospheric CO₂ concentration (parts per million)</i>
eCO ₂	<i>elevated carbon dioxide concentration in the atmosphere</i>
G _s	<i>surface conductance (m s^{-1})</i>
G _c	<i>canopy conductance (m s^{-1})</i>
g _s	<i>stomatal conductance (m s^{-1})</i>
k _Q	<i>light extinction coefficient of shortwave radiation</i>
k _A	<i>light extinction coefficient of available energy</i>
α	<i>initial slope of the light response curve to assimilation rate ($\mu\text{mol CO}_2$ ($\mu\text{mol PAR}$)⁻¹)</i>
η	<i>initial slope of the CO₂ response curve to assimilation rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$ ($\mu\text{mol m}^{-2} \text{s}^{-1}$)⁻¹)</i>
V _{m,25}	<i>notional maximum catalytic capacity of Rubisco per unit leaf area at 25 °C ($\mu\text{mol m}^{-2} \text{s}^{-1}$)</i>
m	<i>stomatal conductance coefficient</i>
MODIS	<i>Moderate Resolution Imaging Spectroradiometer</i>
LAI	<i>leaf area index ($\text{m}^2 \text{m}^{-2}$)</i>
SPAC	<i>soil-plant-atmosphere continuum</i>
LSMs	<i>land surface models</i>
VPD	<i>water vapour pressure deficit (kPa)</i>
RR	<i>rainfall-runoff model</i>
XAJ	<i>Xinnanjiang model</i>
ε _{max}	<i>maximum light use efficiency ($\text{g C MJ}^{-1} \text{PAR}$)</i>
LUE	<i>light use efficiency ($\text{g C MJ}^{-1} \text{PAR}$)</i>
WUE	<i>water use efficiency ($\text{g C kg}^{-1} \text{H}_2\text{O}$)</i>
uWUE	<i>underlying water use efficiency ($\text{g C kg}^{-1} \text{H}_2\text{O kPa}^{0.5}$)</i>
PAR	<i>photosynthetically active radiation (W m^{-2})</i>
f _{APAR}	<i>fraction of vegetation absorbed photosynthetically active radiation (%)</i>
R _n	<i>net radiation (W m^{-2})</i>
f _{Rn}	<i>fraction of vegetation absorbed net radiation (%)</i>
f _s	<i>stress factor (unitless, 0-1)</i>
PET	<i>potential evapotranspiration (mm d^{-1})</i>
PT	<i>potential transpiration (mm d^{-1})</i>
A	<i>assimilation ($\mu\text{mol m}^{-2} \text{s}^{-1}$ or $\text{g C m}^{-2} \text{d}^{-1}$)</i>
PA	<i>potential assimilation ($\mu\text{mol m}^{-2} \text{s}^{-1}$ or $\text{g C m}^{-2} \text{d}^{-1}$)</i>

NSE	<i>Nash-Sutcliffe efficiency</i>
R ²	<i>coefficient of determination</i>
RMSE	<i>root mean square error</i>
PFT	<i>plant functional type</i>

Abstract

This thesis aims to investigate the interaction between hydrological and ecological processes by developing practical and reliable models to quantify and evaluate key water and carbon variables, therefore assist natural resources management and potential decision making implications.

The literature review stands upon the fundamental plant regulation of key terrestrial water (evapotranspiration (ET) and streamflow (Q)) and carbon (gross primary production (GPP)) exchanges and highlights the challenge and requirement of systematic understanding and quantification of these processes using simple and robust approaches considering anthropogenic climate change. Consistent findings following this motivation demonstrate that: (1) Coupled water and carbon fluxes as regulated by plant stomata can be represented by a simple and robust diagnostic model (PML_V2) for simultaneous simulation of ET and GPP at ecosystem scale (examined at 9 Australian eddy-covariance flux sites); (2) Systematic investigation of catchment water (ET and Q) and carbon (GPP) quantity and variation can be achieved by developing a simple semi-process-based ecohydrological model (XAJ-PML_V2, examined at 63 Australian catchments). Preliminary model experiment suggests a 12% increase in Q with only 4% decrease in ET, due to stomata closure in response to a 45% increase in atmospheric CO₂ concentration (anthropogenic climate change); (3) Transpiration (T) estimates as constrained by GPP (using PML_V2 model) exhibit high variation across seasons and sites (while uncertainty remains high), which can partially be attributed to spatiotemporal variations in vegetation index and precipitation (examined at 15 grasslands, 89 site-years); and (4) Coupled relationship between photosynthesis and transpiration enables water based interpretation of carbon process, leading to the development of an analytical method for estimating the maximum light use efficiency (ε_{max}) (that is key for estimating GPP) by implementing the water use efficiency principle (examined at 52 eddy-covariance flux sites across distinct photosynthetic species (e.g., C₃, C₄) and various biome types (e.g., forest, grass)).

This thesis provides systematic understanding of water and carbon processes over ecosystem and catchment scale using modelling approaches. Particularly, two ecohydrological models have been developed to simulate streamflow, evapotranspiration and gross primary production systematically. Variation and uncertainty of water estimates

are investigated based on carbon constraint. An analytical method is developed to evaluate key parameter for GPP estimation based on vegetation water use. To better interpret and quantify key ecohydrological processes under anthropogenic climate change, the models built in this thesis need to be further developed through better model structure, advanced parameterization schemes or multi-data sources.

Key words: ecohydrology, water and carbon interaction, evapotranspiration, streamflow, light use efficiency, water use efficiency, model, climate change